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Azimuthal anisotropy in high-energy heavy-ion collisions at RHIC energies

ShinIchi Esumi

Institute of Physics, University of Tsukuba,
Tsukuba, Ibaraki 305, Japan

Abstract. Directed and elliptic event anisotropy parameters measured in the experiments at relativistic heavy-ion collider are presented. The possible origin of the measured elliptic anisotropy parameter v_2 and its sensitivity to the early phase of the high-energy heavy-ion collisions are discussed.

Keywords: directed flow, elliptic flow, v_2
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1. charged particle v_1, v_2

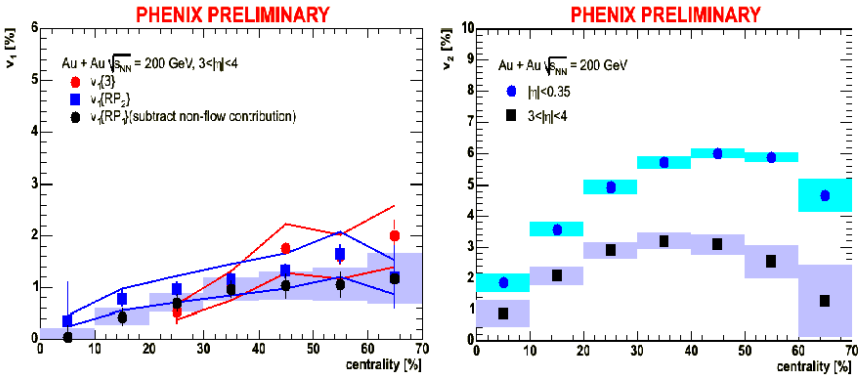

Fig. 1. The charged particle v_1 ($3 < |\eta| < 4$) as a function centrality is shown in the left figure. The charged particle v_2 ($|\eta| < 0.35$ and $3 < |\eta| < 4$) are shown in the right figure.

The charged particle v_1 and v_2 in the forward rapidity ($3 < |\eta| < 4$) are presented as a function of centrality in Fig.1. The 3 different extraction methods are tested to extract v_1. 3 particles selected from 3 rapidity intervals (two particles from the forward and backward rapidities and one particle from the mid- rapidity with the 2nd harmonics are used), the magnitude of v_1 in the forward rapidity is calculated with a knowledge of v_2 in the mid-rapidity.[1] The 2nd method replaces the 3rd particle with the reaction plane (2nd moment) from the mid-rapidity. The 3rd method uses the reaction plane from the opposite rapidity, where the non-flow effect from the momentum conservation is expected, the expected non-flow contribution is subtracted here. The first two methods is expected to be less affected by such a effect. The right panel in Fig.1 shows the v_2 measured in the forward rapidity compared with the mid-rapidity, both are the p_T integrated v_2, it is interesting to note that there seems to have slight different centrality dependence for two rapidity slices.

2. Identified particle v_2

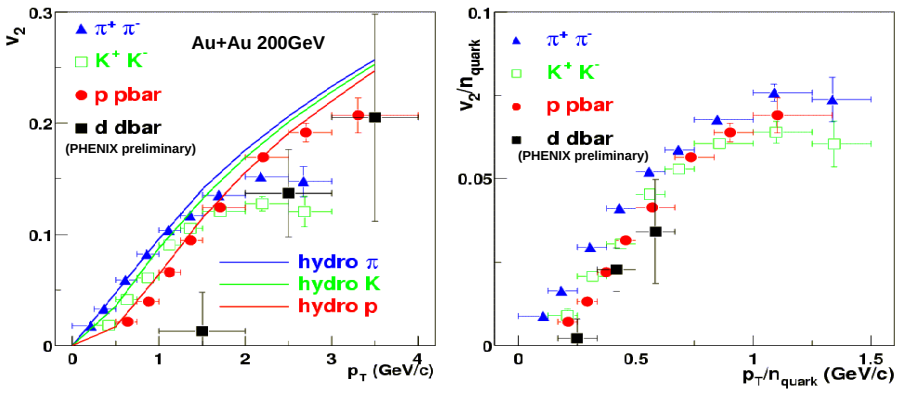

Fig. 2. The identified particle v_2 ($|\eta| < 0.35$) for π^{+-}, K^{+-}, p+$pbar$ and d+$dbar$ are shown in the left figure. The right figure shows the same for the number of quark scaled in both v_2 and p_T.

The identified particle v_2 in the mid-rapidity is shown in the Fig.2[2] and compared to a hydro model.[3] The reaction plane is defined in the forward and backward rapidities and the particle identification is given by the time of flight detector. The right panel shows the number of quark scaled v_2, the agreement between different particle species might tells us the v_2 is already generated during the partonic phase (before the hadrons are formed), but there seems to be some remaining mass ordering which might come from the later stage (hadronic flow), although the dif-

ference between pion v_2 and the other hadrons is well described by the feed-down effects.[4, 5]

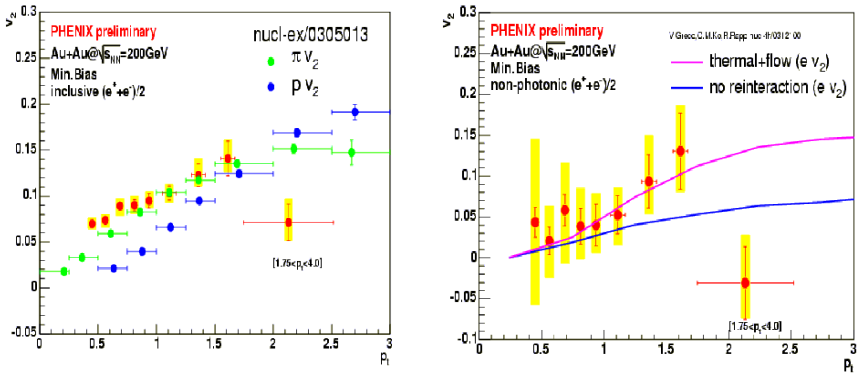

Fig. 3. The inclusive electron/positron v_2 is shown in the left figure. The right figure shows the v_2 of subtracted charmed electron contribution.

The electron and positron v_2 are measured as shown in the left panel of the Fig.3 in order to extract the charm quark v_2, since the single electron momentum distribution is measured to be dominated by the semi-leptonic decay contribution of the open charm at high p_T.[6] The electron and positron are identified by the ring imaging Cherenkov detector and the electro magnetic calorimeter. Using the relative yield of open charm in the inclusive electron momentum spectrum and the measured v_2 of the dominant π^0 contribution, the v_2 of charmed electron are extracted as shown in right panel in the Fig.3 and compared with a model.[7] The present statistics does not allow us to conclude on the charmed quark v_2.

The inclusive photon v_2 are measured and compared with π^0 v_2 as shown in the Fig.4.[8] The photon and π^0 are measured and reconstructed with the electro magnetic calorimeter. Using the direct photon enhancement with respect to the π^0 decay contribution, which seems to be consistent with the binary collision scaled production of the direct photon,[9] the direct photon v_2 would be extracted in the future run with much higher statistics.

3. Origin of v_2 and non-flow

The assorted correlation functions are shown with one particle in the full p_T reference and another in the p_T window described in the Fig.5. From the left to right, (1) pure harmonic function, (2) pure harmonic + near side Gaussian function, (3) pure harmonic + near/away side Gaussian function, (4) pure harmonic where the magnitude of v_2 fixed by the measurement, only the fitting functions are different

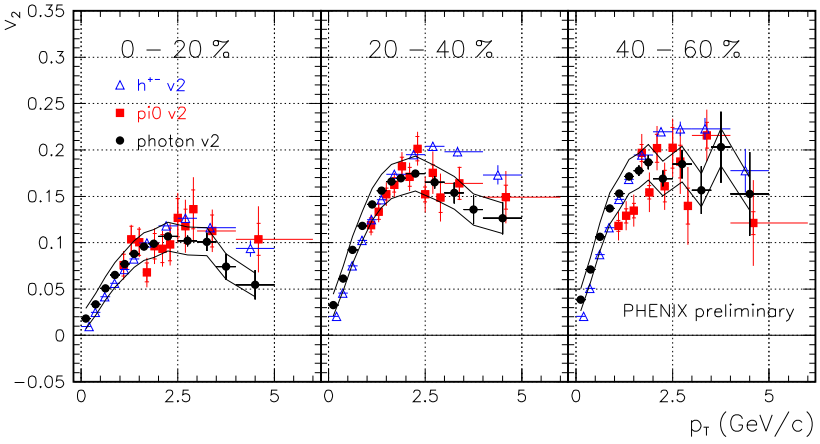

Fig. 4. The inclusive photon v_2 compared to the π^0 and h^{+-} v_2 as a function of p_T for 3 centrality bins.

from the left to right, while the data are the same (top for the lower p_T, and bottom for the higher p_T windows). It is clearly demonstrated that the extracted magnitude of v_2 from the pair azimuthal correlation depends on what type of function is used to fit the measured correlation in order to remove the non-flow contribution. The comparison shows that the measured correlation suggests that there is a need to have a rather wide away side Gaussian-like (although it does not have to be a Gaussian shape) contribution.

The Fig.6 shows two particle azimuthal correlation with trigger particle in- or out-of- reaction plane. The fitted function has an fixed shape which is given by an independent measurement of v_2 with respect to the reaction plane defined in the forward rapidity and the reaction plane resolution.[10] The correlation functions are mostly described except the clear near side jet contribution seen at around 0 degree. However looking at more precisely the difference between in-plane and out-of-plane as shown in the right panel of the Fig.6, where the expected flow contribution is subtracted, the enhancement of in-plane correlation over the expected flow contribution seems to be larger compared to one from the out-of-plane correlation for the both near side (0 degree) and away side (180 degrees). This might be an indication of the coalescence of the jet-fragmented quarks, which depends on the orientation with respect to the reaction plane and this could be one of the source of v_2 on top of the initial pressure gradient.

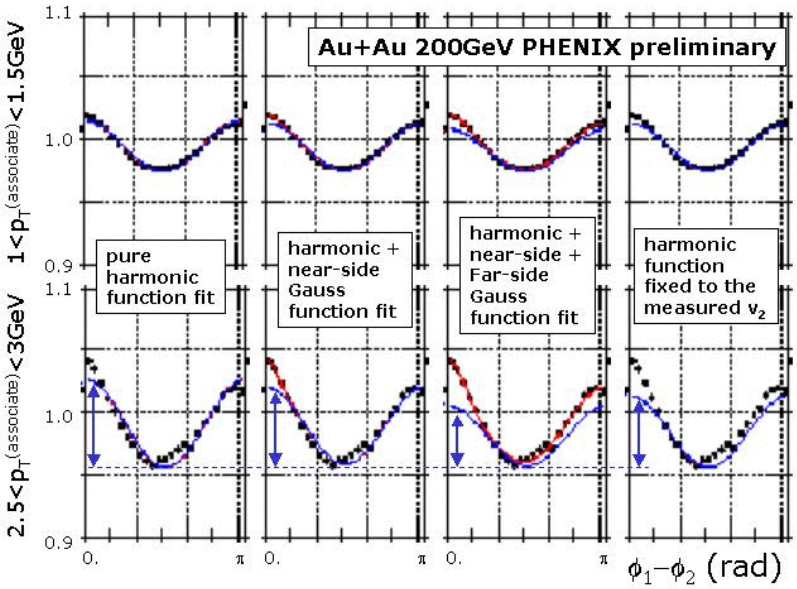

Fig. 5. The two particle correlation for two p_T bins (top and bottom) and different fitting functions (left to right) to extract v_2 are shown.

4. Conclusions

The charged particle v_1 and v_2 as a function of centrality at forward- and mid-rapidities. The measured identified hadron v_2 shows rather good agreement with quark number scaling by taking into account the feed-down effect on pions, which tells us the v_2 might have been formed during the partonic phase, however there could be another indication of the flow in later stage after hadronization in the remaining mass ordering of v_2. The inclusive electron and photon v_2 measurements in the future run with large statistics will provide the charm quark and direct photon v_2. Combined analysis with two particle correlation and reaction plane orientation have opened a new dimension of the event anisotropy and jet tomography analysis and have an indication of another origin of the elliptic flow.

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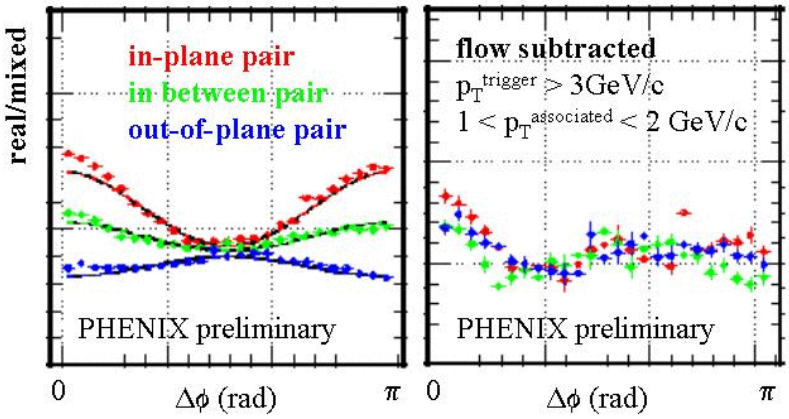

Fig. 6. The two particle correlation with respect to the different reaction plane orientation. The fitted function is given by the measured v_2 with respect to the reaction plane and reaction plane resolution.

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